Use of the Carbon Arc and Burning Magnesium as Thermal Sources for Experimental Burns *

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Introduction

THE ATOMIC BOMBING of Hiroshima and Nagasaki caused a large number of casualties from skin burns due to a short exposure from high intensity thermal radiation. In 1947, we began studying these "flash burns" in the laboratory,[14] and in the last ten years several thermal sources for this purpose have been investigated. To date, we believe that the carbon arc furnace is the best source for small area burn production, and that the burning of magnesium flash powder is the best method of creating large area flash burns. The development and performance of these two thermal sources are described.

This equipment has the added advantage of precise control of the thermal dose so that research may be done on the factors which govern the local burn. It has been known since the work of Moritz and Henriques [13] that both time and temperature are critical in the degree of severity of burns. Yet many investigators have reported observations on physiologic changes from burns produced by flame, steam, hot water or a hot iron, in which these factors were not accurately controlled. The lesions created in successive experiments differ in severity unless the thermal dose is controlled.

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The Carbon Arc

In 1947, consultation with Dr. E. O. Hulburt, Director of Research, Naval Research Laboratory, led to the suggestion that focusing the beam from a carbon arc on a test object might be a good method for producing radiant energy burns. It was then found that carbon arc searchlights were already being used for a similar purpose at the Material Laboratory of the Brooklyn Naval Shipyard under the direction of Dr. Rudolph Langer. We set up such an arc, and at the same time explored other possibilities. The "exploding wire" of Anderson,[1] spark discharge from a bank of condensers and discharge from an Edgerton tube [6] were tried but were not satisfactory for our needs. A solar furnace was considered but discarded as impractical in our climate. High temperature furnaces, using a bank of gas burners, oxyacetylene flame, burning aluminum in oxygen or an electric current through graphite resistors were tried elsewhere. Such furnaces suffer from such disadvantages as inadequate thermal energy output, unsuitable spectral distribution or excessive cost. We concluded that the focused beam from a carbon arc was the best method for producing the small area burns which we wished to study.

Figure 1 illustrates the optical system for focusing the beam from a carbon arc by means of two parabolic mirrors. Our first equipment of this sort included a 24-inch Army carbon arc searchlight with a rotary shutter.[14] This was satisfactory for small

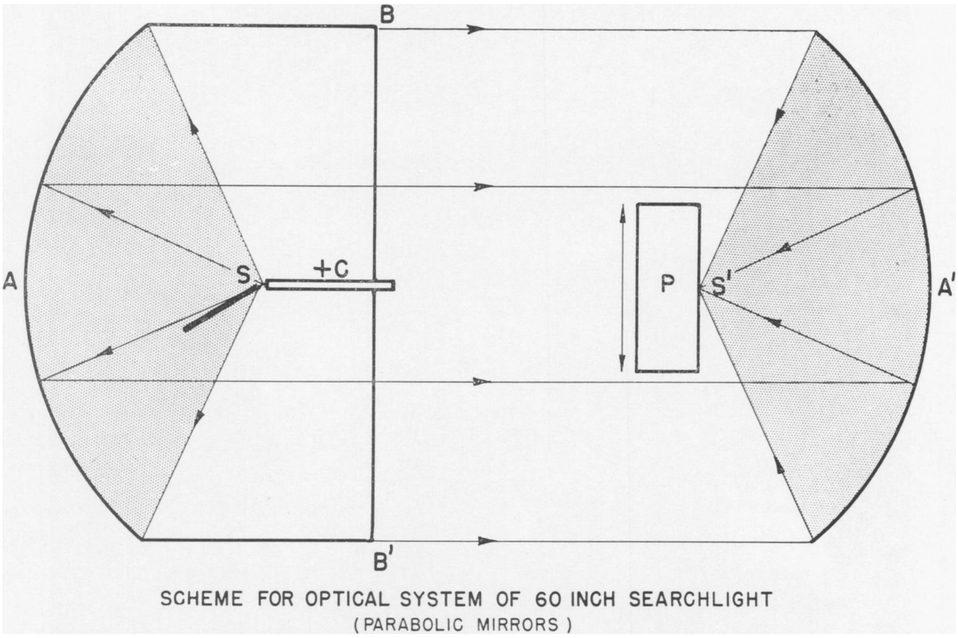

FIG. 1. The parabolic mirror of the searchlight, A, reflects the rays from the carbon crater, S. These are focused by a second parabolic mirror A′ at the spot S′. The animal P is exposed on a moving car having a known rate of traverse. A strip burn is produced.

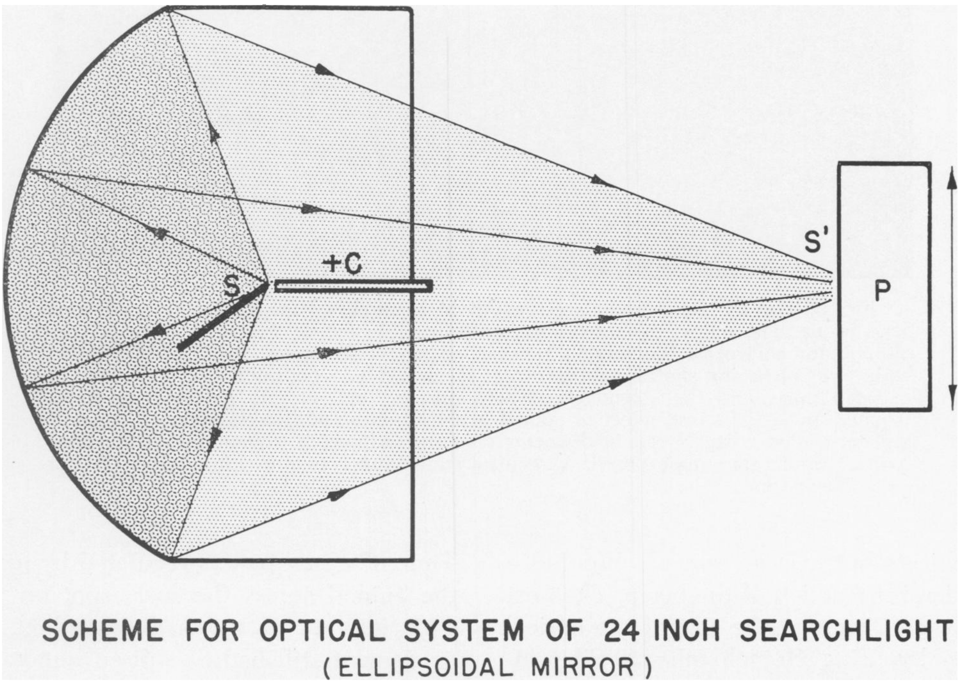

FIG. 2. The primary focus of the ellipsoidal mirror is at the carbon crater S. The secondary focus, S′, is 52 inches from the mirror where the image is enlarged about five times to expose the animal, P.

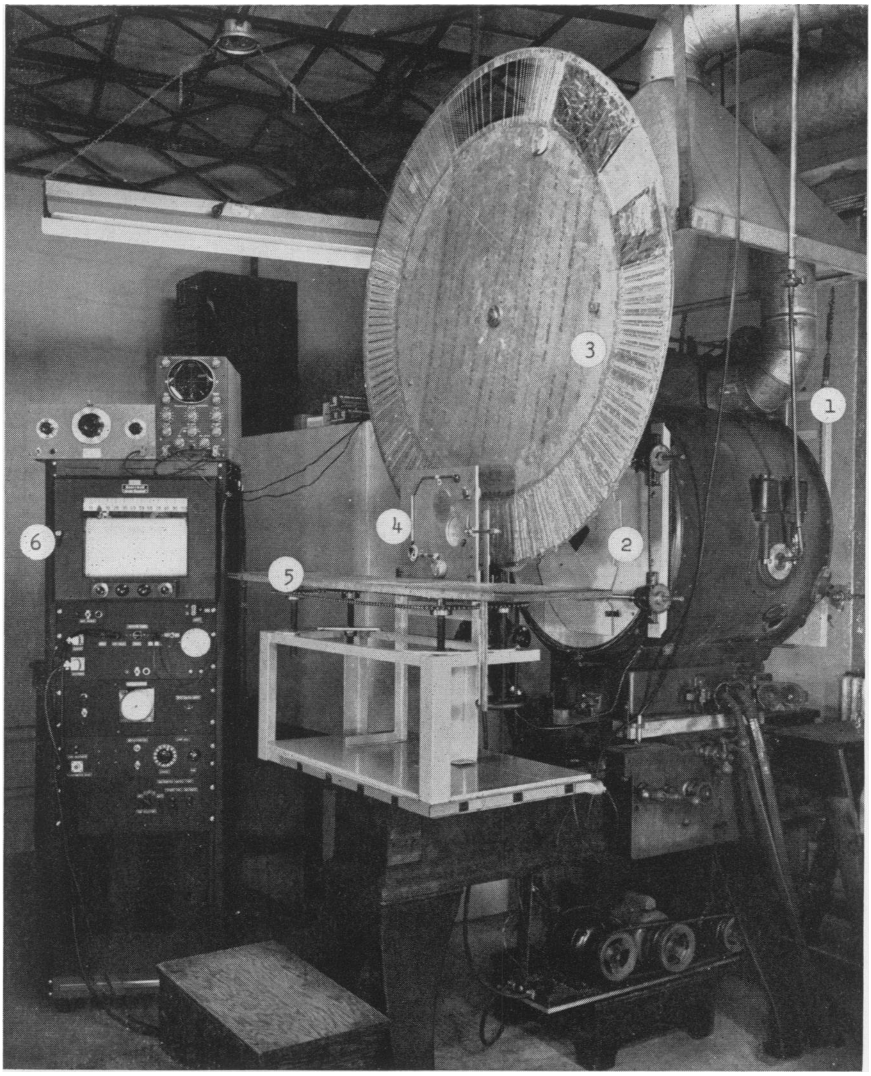

FIG. 3. The 24-inch carbon arc searchlight as modified for producing small area flash burns. The ellipsoidal mirror has an adjustable mount (1). One type of diaphragm for control of the radiant thermal energy is shown at (2). For illustration both types of timing shutters are in place: the wheel (3) for simulating the shape of a bomb pulse and the solenoid activated opening and closing shutter (4) for a "square" pulse. The test object or animal is placed on an adjustable table (5) against a water-cooled port 1.7 cm. in diameter (not shown) which is centered on the focal spot and limits the area exposed. All control equipment is mounted in a panel (6) for ease of operation.

test objects but a large animal obscured a considerable fraction of the beam. The next step was to increase the size of the optical system by using 60-inch mirrors. This increased the radiant power obtainable to about 90 cal./cm.^{2}-sec. and decreased the relative obscuration by the test animal. Time of exposure was regulated by moving the animal across the focal spot on a car with its rate of traverse controlled. This equipment still had two disadvantages: its focal spot was very small and the angle of the rays from the edge of the mirror was about 60°.

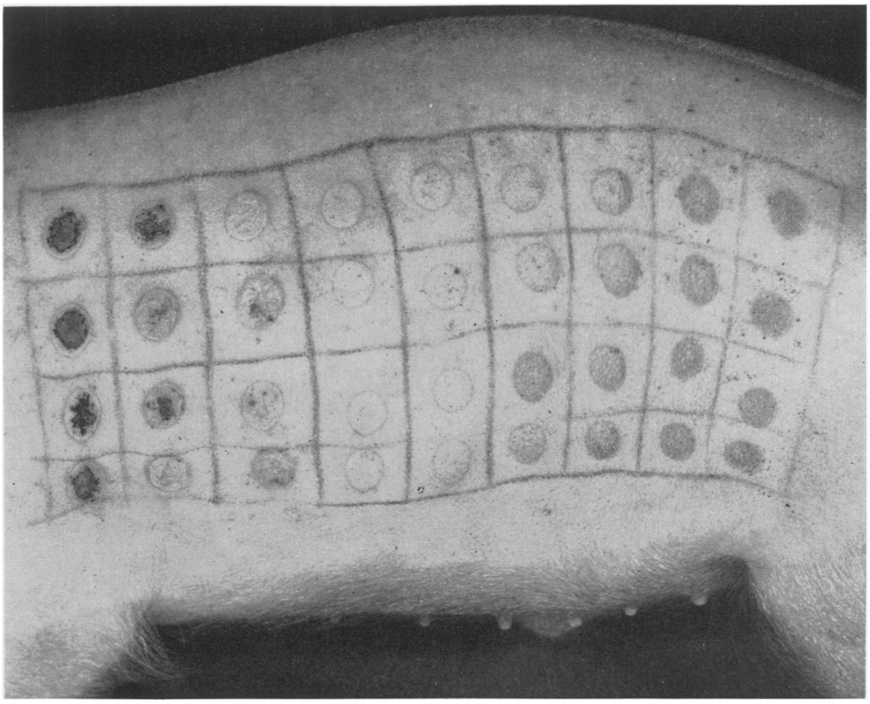

FIG. 4. Thirty-six small area burns from the carbon arc source may be placed on one side of a white pig. By using both sides 72 observations are made on one animal. In this illustration the lesions increase in severity from erythema on the right to carbonized burns on the left. In experimental work the lesions are randomized.

Meanwhile development of carbon arc furnaces using essentially the same optical system was being carried on at the Brooklyn [12] and San Francisco [3] Naval Shipyards, and at Richmond.[16]

In order to overcome the disadvantages inherent in the use of two parabolic mirrors, we changed, in 1950, to an optical system in which the 24-inch parabolic mirror of an Army searchlight was replaced by an ellipsoidal mirror (Fig. 2). This is positioned by an adjustable mount to place the positive carbon crater at the first focal point. An image of this source, enlarged about five times, is then obtained at the second focal point with the greatest angle of incidence being only about 16°. This arc uses a National Carbon Co. "Ultrex" 10 mm. positive carbon with an arc current of about 140 amperes. The spectral distribution corresponds approximately to that from a black body at 5,800° K. The equipment is shown in Figure 3.

At the exposure plane the maximum irradiance is 34 cal./cm^2.-sec. for this system. An adjustable diaphragm and attenuating screens are used to control the irradiance, which can be reduced to as little as 0.1 cal./cm^2.-sec.

For producing a "square pulse," a shutter consisting of two light aluminum vanes, one for opening and one for closing, actuated by rotary electrical solenoids is used. Synchronous motor driven cams provide precise timing of exposures from 0.1 second to 100 seconds or more.

For obtaining a "shaped pulse," a wheel was devised [11] 50 inches in diameter, mounted with its edge just below the converging beam of radiation. Radially disposed pickets, adjusted for width and spacing, cut into the beam and give the degree

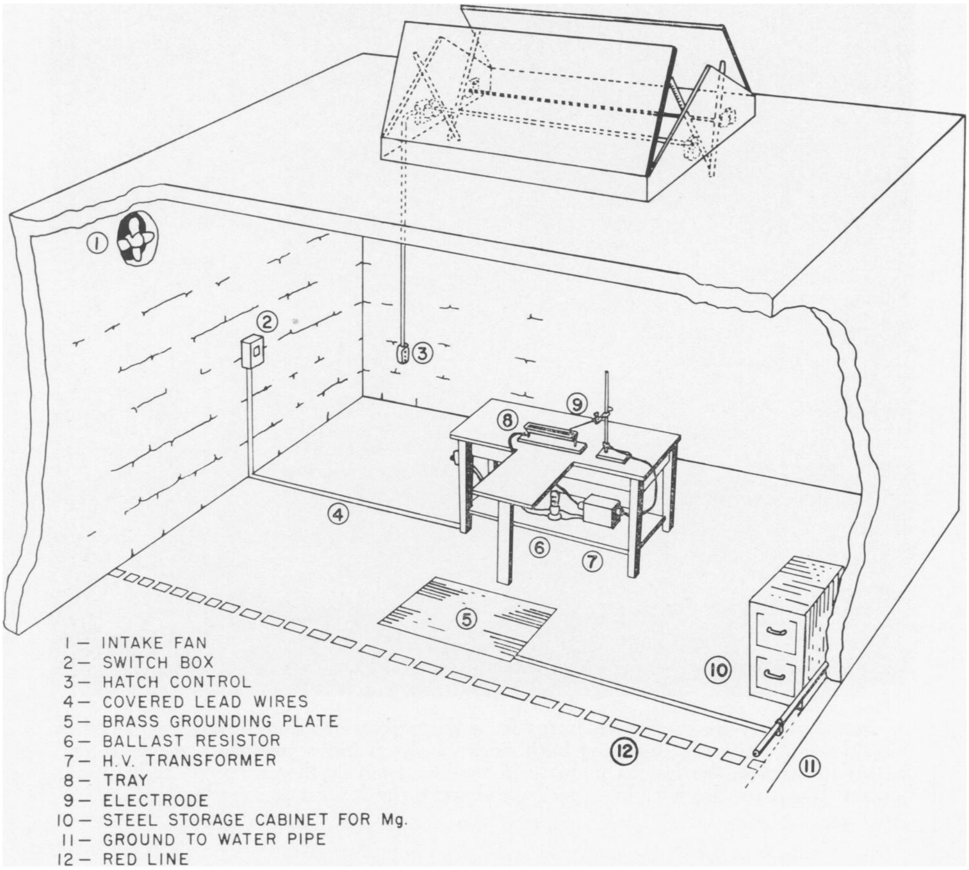

FIG. 5. A diagrammatic sketch of the laboratory for firing magnesium flash powder. The animal is placed on the table beyond the tray (8). Safety precautions must be completed before crossing the red line (12).

of attenuation desired. The total time of exposure is controlled by the speed of rotation of the wheel, so that pulses with a wide variety of shape and duration may be obtained.

The characteristics of the irradiation from such an arc source may be measured in several ways. To obtain the absolute value of the output energy, a copper sphere calorimeter designed in this laboratory [2] is used. The spatial distribution in the exposure plane is obtained by probing the spot with a photo cell behind a pin point opening. The spectral distribution was determined by a special spectrophotometer [10] constructed for this purpose. Appropriate filters may be placed in the beam if it is desired to alter the spectrum of the radiation applied.

The exposed area on the test animal is limited by means of a water-cooled port which is 1.7 cm. in diameter. The spatial variation of irradiance within the central circular area of 1 cm^2. is about 12 per cent.[2] This small area permits as many as 36 burns to be placed on each side of a 12 Kg. white pig (Fig. 4). Results are analyzed by statistical methods.

The carbon arc furnace has the advantages of high and constant irradiance, good reproducibility, and ease of control of the exposure parameters. These permit analysis of the factors which modify burn severity, where precise control of the thermal dose

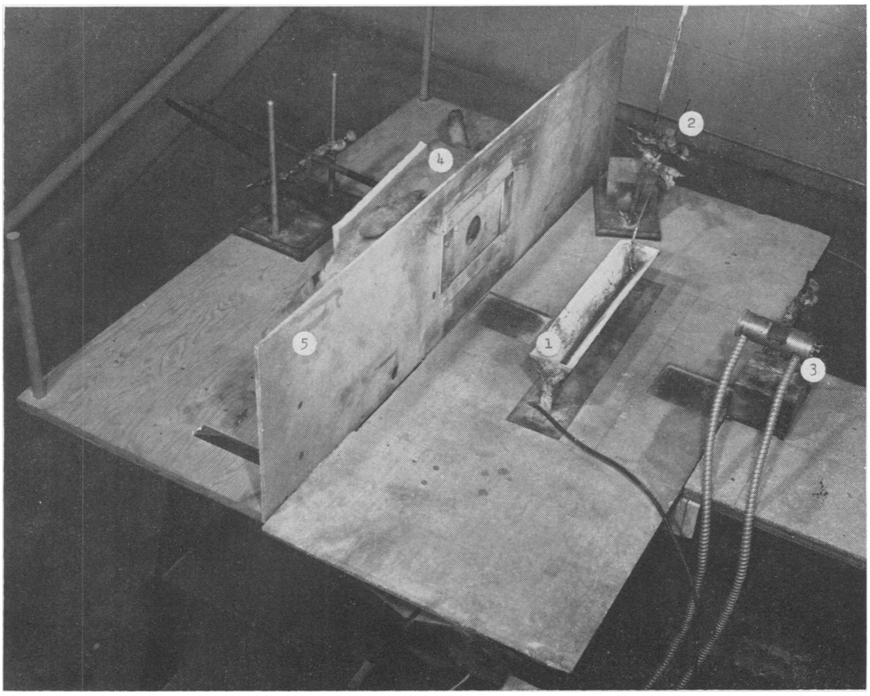

FIG. 6. Closeup of the equipment for firing magnesium. The flash powder is spread across the Y-shaped tray (1) and detonated by the electrode (2). A calorimeter (3) is on one side at the same distance from the charge as the pig (4) on the other side. In this illustration the animal is shielded by a transite plate (5) except for a 3-inch circular opening. Larger areas are exposed through the rectangular opening or the whole side of the pig may be burned if the transite shield is removed.

is obligatory, and facilitate research on the changes which occur in radiant energy cutaneous burns.

The Magnesium Source

In 1943, Fauley and Ivy [7] used burning magnesium powder as a flash source. We tried this in 1947,[14] and found it superior to other combustibles such as gun powder, high octane gasoline or thermite. Its time of ignition could be varied from 0.3 to about 2.0 sec. by additives, but it had the disadvantage of producing large amounts of white smoke which filled the laboratory and disturbed others. Firing out-of-doors on the roof was tried but was found to be unsatisfactory due to variations of wind and weather. Finally, a special firing room was built to overcome these difficulties.

The laboratory for firing magnesium flash powder is illustrated in Figure 5. It is a concrete block structure, 28 ft. × 15 ft. × 11 ft. with a concrete floor having a drain and a steel trussed roof. The walls are strong enough to withstand the low blast pressures from laboratory size charges. Smoke is evacuated through a 6 ft. × 6 ft. hatch in the roof, having hinged, motor-driven covers. Forced draft from an intake fan helps to evacuate the smoke through this hatch.

Satisfactory burning of magnesium requires shaping of the flame, control of ignition time and prevention of injury of the personnel from blast or heat. The flame is shaped by a Y-shaped tray (Fig. 6), 15 inches long with a cross-section of 1 inch at the bottom, flaring to 3 inches at the top. This prevents a lateral spread of the flame which would give contact burns on the test object.

The time of burning is controlled by the amount of oxidizing agent in the blend.

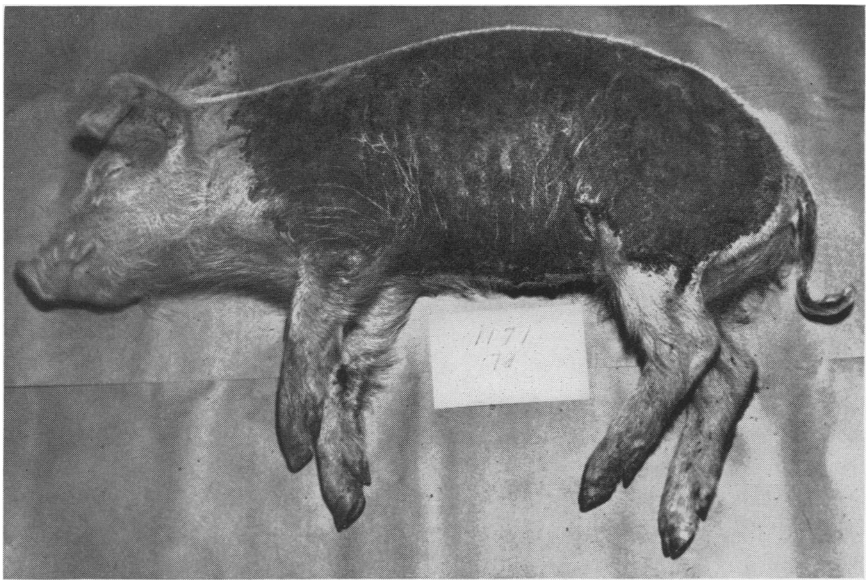

FIG. 7. A large carbonized flash burn of about 20 per cent body area produced by burning magnesium flash powder. Note the leathery eschar formed, which acts as an impervious covering to the lesion. The head, hooves and genitalia are protected to avoid unnecessary discomfort. This animal has been anesthetized for taking a biopsy.

The present blends are made to have an ignition time of 0.3 to 2.0 sec., and if no more than 200 cm. of powder are used, blast is not a problem. Some blast occurs with a burning time of 0.3 sec. and becomes excessive with times much below this.

Originally we mixed our own material under a hood by sifting the compounds through 150-mesh screen, after which they were blended, weighed and packaged. This was both tedious and hazardous so arrangements were made to purchase ready mixed powder in 50 gram packages from Kilgore, Inc., of Waterville, Ohio. The average composition by weight of this material is:

Barium nitrate	40.5%
Potassium nitrate	13.5%
Magnesium, Grade B	19.0%
Aluminum, Grade A	27.0%

Calibration of Magnesuim Flash Powder: Radiometer measurements of the rate of energy released from a powder burning in 0.7 sec. show a curve of intensity which rises sharply to a maximum at 0.2 sec. and then falls more gradually to the base line.[15] The general shape of this curve is not unlike that of the radiant thermal energy from the fire ball of an atomic bomb.[8]

A cone calorimeter developed by Davis [4] was used to measure the radiant energy incident at 15, 30, and 45 cm. from charges of 50, 100, and 150 Gm. of the flash powder. Under these conditions measurements showed a range of 2 to 22 cal./cm.^{2} with a variation of $\pm$ 10 per cent. An example of a large area, carbonized burn caused by an exposure to 150 Gm. of magnesium flash powder is shown in Figure 7.

The severity of the burn may be assessed by surface appearance and by its depth. Biopsies taken at 24 hours are stained by the method, developed in this laboratory,[9] to give objective differentiation of the depth of burn in the dermis. Damage is measured to the deepest point seen in the section by a micrometer in the eyepiece.

Discussion

The equipment described was developed as a laboratory source of radiant thermal energy which would simulate, as accurately as possible, the thermal radiation from atomic bomb explosions. This cannot be absolute, for some of the characteristics of bomb radiation are imperfectly understood while others may vary from weapon to weapon. A useful laboratory source must not only reproduce the major characteristics of the thermal energy from atomic weapons, but also permit the alteration of exposure parameters to allow simulation of the effect from atmospheric attenuation, distance and weapon yield. Thus the laboratory source must be flexible in terms of flux density, spectral distribution and form and duration of the radiant pulse. However, this flexibility cannot be achieved by sacrificing stability of calibration if reproducible results are to be attained.

While the quality, form and duration of atomic bomb radiation may be closely approximated by laboratory equipment, it is probable that it can never simulate the exposure geometry from actual weapons. In our area of interest for thermal effects, the geometry of bomb radiation corresponds to that of a distant point source with consequent plane parallel radiation impinging upon the target. All surfaces of the receiver normal to the source will be uniformly exposed, and intervening objects will cast sharp shadows, so commonly observed in Japan. This type of geometry cannot be duplicated in the laboratory.

The carbon arc lamp gives a steady and reproducible source of radiation. Accessory equipment permits convenient, flexible and accurate control of spectral distribution, form, and duration of exposure. Its disadvantage is the limited size of a uniform exposure so that it can only be used to study small areas. Where the factors which modify the severity of the local burn lesion are to be evaluated, it is a highly precise tool and is the method of choice for carefully controlled quantitative work.

In situations where a large area of exposure is desired, we have found burning magnesium flash powder to be a suitable source. It is the only method devised to date for creating, in the laboratory, a large area flash burn by conditions that are comparable to those resulting from atomic weapons. The total energy delivered by this incendiary is controlled by the amount of material ignited and the source-receiver distance. Calorimetric studies indicate a surprisingly good reproducibility of the thermal energy delivered, with less than 10 per cent variation from shot to shot. The spectral distribution and form of the pulse are fixed by the characteristics of the flash powder. Within these limitations, this source is very useful for large area radiant energy burn studies.

As our investigations have continued we have become increasingly interested in the fundamental physical and chemical changes that enter into the production of cutaneous burns and how these modify the severity of the lesions. It is felt that only by such research will one arrive at some of the practical answers that are needed. This has required precision equipment. It is our opinion that the development of the thermal sources described has had the dual advantages of experimentally simulating bomb radiation, and creating a laboratory tool for the exploration of the mechanisms involved in cutaneous burns.

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